

NEW RAPID CASTING TECHNIQUES FOR COMPETITIVE MOTOR SPORTS

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Abstract

Casting components utilizing free form manufacturing techniques to produce investment patterns have in recent years been overshadowed by the promise of Direct Metal machines. Despite this casting vendors continue to work diligently to make the creation of extremely complex components as an almost common place occurrence. This paper examines the work of CRP Technology and its creation of Windform® PS to advance casting techniques and ultimately produce front and rear uprights for the new “Epsilon Euskadi ee1” for competition in American Le Mans Series and 24 hours of Le Mans 2008. Developed and manufactured utilizing the “CRP Rapid Casting Method” these Titanium Rapid Castings highlight the hard and complex work involved in making this extremely difficult task look easy. The process is examined and outlined to help others understand the work involved.

Introduction

The collaboration between Epsilon Euskadi and CRP Technology began at the end of 2007 with the aim of optimizing some crucial safety features of the new Epsilon Euskadi ee1 for the Le Mans Series and the 2008 Le Mans 24 Hours: front and rear uprights cast in titanium using the CRP Rapid Casting method.



Picture 1: Epsilon Euskadi ee1 LMP1 Team

The key to the success of the project was a close partnership between CRP Technology and Epsilon Euskadi that began from the CAD drawings through the first prototype and into the final construction phase.

The ee1 project began in 2004, the year in which Joan Villadelprat, with his 30 years of experience, took over the reins of Epsilon Euskadi (until then only a team in the Renault World Series). 2005 saw the official launch of

the ee1 project, under the technical direction of John Travis, previously an engineer with Lola and then with Penske and in F1. At the end of 2007, the technical management of the project was taken over by Sergio Rinland, who in his turn had a past in F1.

CRP Technology s.r.l. has been one of the most famous and perhaps representative names in racing environs for more than 30 years. It has had an important role in the success of many teams in F1, Moto GP, Rally Raid, ALMS and the World Rally Championship.

The main activities are:

- HQ & HSM CNC (high speed and high quality machining with 3, 4 and 5 axis)
- Rapid Casting (lost wax casting with RP patterns) in Titanium, Aluminium, Steel alloys or Superalloys
- New ULTRArapid Casting, optimized for Aluminium alloys
- Rapid Manufacturing and Rapid Prototyping services

- Rapid Manufacturing & Rapid Prototyping composite materials (WINDFORM® family) production and sales materials
- Total Quality Management (ISO 9001:2000 company certificated)
- R&D: continuous research on materials like metallic alloys, plastic materials and new manufacturing processes development
- Reverse Engineering

Most of the company's success is due to the collaboration that has been created with the various teams. CRP is involved right from the initial stages of design and development, and its innovative approach to the use of materials and original technologies is widely recognised by the racing car industry. Just one of the many examples is the winning partnership that it developed in 2006 and 2007 with Mitsubishi for the Paris-Dakar project.

Rapid Casting - The Procedure

The CRP R&D department is involved in the Rapid Casting technology since 1997.

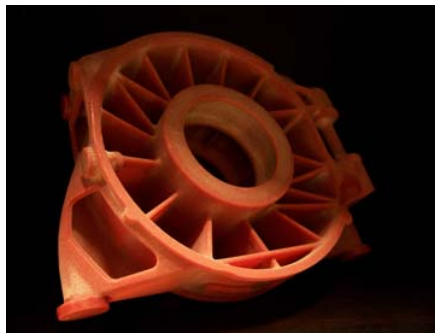


In 1998 CRP Technology began to work alongside the Minardi F1 team, supplying them the engineering process, the manufacturing process optimization and the manufacturing of front and rear uprights: they began from the study of the Titanium Rapid Casting process.

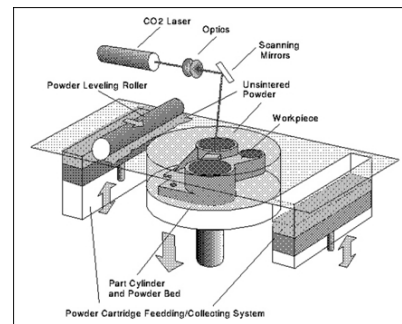
Picture 2: F1 Upright –Titanium Rapid Casting

Rapid Casting is based on the combination of Rapid Prototyping technology, to manufacture the disposable pattern, and Investment Casting technology (Investement casting).

The RP disposable pattern is made by a consecutive overlapping of layers, using the Selective Laser Sintering technology. The system doesn't require any support because the piece is held up by the non sintered powders, therefore giving complete freedom of shape.



Picture 3: Disposable pattern: laser sintering and red wax infiltration



A schematic drawing of an SLS process.

Picture 4: A schematic drawing of an SLS process

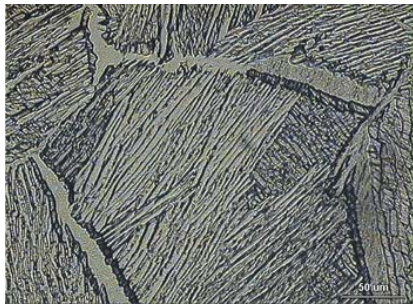


The Rapid Casting procedure is composed of a number of steps:

- A disposable pattern is made through RP technique and polystyrene material
- The pattern undergoes wax infiltrations (immersion and capillarity) to increase its strength (to avoid handling breaks);
- The pattern is immersed in a ceramic bath:
- Slurries and stuccoing and exsiccation;
- The lost pattern is evacuated: dewaxing with flash firing or in an autoclave and subsequent sintering of the ceramic shell
- Alloy casting with inductor or voltaic arc;
- pouring, cooling, reduction of the shell, shot peening, gate cutting, heat treatments

Picture 5: Example of disposable pattern, ceramic shell and casting

Isotropy By Compensation



The casting structure is formed of an aggregate of grains or polyhedral crystallites which produce isotropy compensation. In a solid metal and a CNC-machined part (such as welded part) they are anisotropic. A body is assumed isotropic when it has normal and shear components of stress on any plane through a point of that solid, and homogeneous when this situation is valid for any point of the solid.

Picture 6: Micrography in which it's possible to see the alpha-beta structure in the grain center and the typical annealed alpha structure at the grain border.

Normally a CNC- machined part from a forged round bar, plate or billet has an anisotropic structure. In fact, as results from the machining process stress, the structure of the forged material is composed by an aggregate of grains or polyhedral crystallites that are oriented in the space toward a unique and preferential way/direction.

On the other hand, in the casting process the structure of the piece is modified and the aggregate of grains or polyhedral crystallites are oriented at random. Therefore, the new structure obtained is definite—"an isotropic structure by compensation."

Isotropy has great advantages, such as stiffness of the parts, reliability and FEM calculations are very close to the real behavior. For that reason, Rapid Casting (since it's a casting process) allows to produce parts with quality and properties (durability and reliability of the part) very close to a CNC-machine part, but with the advantages of the casting part, given by the isotropy structure, as stiffness and fewer design limitation.

Moreover, Rapid Casting with laser sintered patterns allows complete shape conception freedom: thus reducing undercut and tool path problems during CNC machining.

It's therefore possible to create the product along its mechanical stress axes, and to obtain a perfect reproduction of all details of the RP pattern, with tolerances and surface finishing of a very high quality (such as fully machined parts). It's what we can call DFFF: Design For

Functionality & Fun, thus allowing you to think about what you need and not how to machine it (Design for Functionality instead of Design for Manufacturing).

The Materials

In 1997, CRP began to study laser sintering technology to manufacture disposable patterns using Polycarbonate and Trueform materials. Although these materials were not suitable for titanium alloy pouring—because the high ash content remaining inside the shell reacted with the titanium alloys, producing porosity and scrubs—they proved perfect for steel and aluminium alloys.

Therefore, CRP decided to develop new materials for rapid casting patterns sintering, and partnered with DTM Corp. in 1998 to be the first to use rapid casting for hard to cast shapes such as F1 uprights and gearboxes, and alloys such as titanium. They were first to optimize a polystyrene material for laser sintered patterns—CastForm®. For many years CRP used Castform®, from DTM Corp. for the sintered disposable patterns.

In an effort to solve issues, the CRP R&D department built on the knowledge and experience in rapid prototyping, casting and machining to become experts in the rapid casting process. This work led to CRP being recognized as a leader in the use of rapid casting for motorsport applications throughout the world. These efforts have now yielded a breakthrough in this arena.

Today the result is Windform® PS.



Windform® PS is a new polystyrene based material, suited to produce complex investment casting patterns. The sintered

patterns are porous enough too allow wax infiltration, and therefore become easy to handle and to finish.

Improved properties, compared to other polystyrene materials already available on the market, and that make the difference, are:

- Improved surface quality and details reproduction
- Less “curling” effect on the first layers
- Very low ash content, therefore perfect suitable for highly reactive alloys, such as Titanium alloys too, besides aluminium, magnesium, steel and nickel based alloys.



Picture 7: Complex investment casting patterns made by Windform® PS

It's particular suited for the foundry and RP market since the main applications are:

- Complex investment casting patterns
- Casting with highly reactive alloys, in addition to typical cast alloys.

CRP's goal was to use Rapid Casting for very high performance parts, primarily for F1, therefore having very complicated shapes and geometries, and using the best alloy available for the casting procedure: Ti-6Al4V.

Thanks to CRP Method and the continuous R&D on polystyrene based material, the production of ash during the evacuation of the ceramic shell has been reduced: the ash, when

in contact with the titanium, produces chemical reactions that damages the casting, and have therefore to be eliminated before pouring the cast metal in the ceramic shell.

This allowed CRP Technology to become the first to use rapid casting for very hard-to-cast shapes (such as F1 uprights and gearboxes) and alloys (such as titanium).

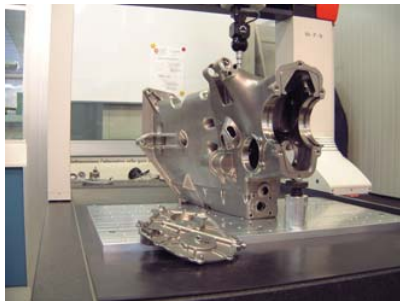


Picture 8: Minardi Titanium Rapid Casting gearbox 2000



Picture 9: F1 Upright – Titanium Rapid Casting

The Ti-6Al4V is the most widely used alloy in motorsport and aerospace markets, particularly the one used by CRP. It contains 6% aluminium and 4% vanadium, an excellent combination of stress resistance and toughness, with optimal wear resistance.



Positive aspects of Ti-6Al4V are:

- lightness (density 4,43 g/cm³)
- high specific Ultimate Tensile Strength (225,73 MPa/(g/cm³)) (UTS 1000 Mpa)
- bio-compatibility
- low thermal and electrical conductivity
- corrosion and stress-corrosion resistance (SCC)

Picture 10: Minardi Titanium Rapid Casting gearbox 2001

Advantages given by heat treatment of the casting are:

- stress reduction
- ductility
- workability
- dimensional and structural stability

Titanium casting has a really high reactivity and that's the reason why it needs in addition:

- Chemical milling, to remove the alpha case created when the metal touches the ceramic shell;
- HIP: Hot Isostatic Pressure applied in an inert atmosphere (argon) to eliminate micro-porosity and shortage of material inside the casting;
- TIG Weld repair in inert atmosphere to fill in porosity or HIP hollows, tested with real time RX inspections;
- Shot peening: under-control shot peening to reduce stress and increase fatigue resistance.

The final product is then fully CNC machined and undergoes a complete testing (material, RX, FPI, HT, etc...) ISO 9001:2000 certified.

This technology was immediately highly appreciated by customers: it provided durability and reliability of the part (a casting is naturally isotropic for compensation), fewer design limitation to lightener (pockets) and get stiffer (adding ribs) the part during the racing season. CRP decided to continue to improve the Rapid Casting process because they know what their customers need: at 300kmh quality isn't optional, it's your life.

Motorsport case study: Epsilon Euskadi's Upright development

The synergy between Epsilon Euskadi and CRP Technology has, therefore, been fully achieved in the development of one of the key components of the suspension system, as well as the core business for CRP: titanium uprights.

In particular, considering the vast experience that CRP has gained in Formula 1 and in WRC (World Rally Championship) in the research and manufacture of the parts mentioned above, the specialised technicians within the company are devoted to engineering Epsilon uprights with the use of high-precision investment casting, in titanium alloy, with patterns made in Rapid Prototyping.

Sergio Rinland confirms: "CRP is one of the most experienced companies when it comes to Titanium castings, I have work with the Cevolini family since a long time. They are professionally competent and they understand the Motorsport business like not many suppliers do."

The upright in fact is a critical and supporting part of the suspension core: in actual fact it is the connection between the wheel group (Tyre, rim, brake disc, Hub), on one side, and the suspension unit (lower and upper wishbone, pushrod arm, steering arm or toe-in arm), on the other. The brake calliper is also connected to it.

The criticality of the piece lies in the fact that it is considered an unsuspended mass that is subject to a notable quantity of stress, owing to the speed dynamics of the vehicle, or derived from braking and shifting of the suspensions, which generates continuous load transfer.



Picture 11: Uprights on the car. The criticality of the piece is due to the notable quantity of stress that is subjected to.

The most critical aspects are manifested when all these motives of stress occur together, for example upon hard braking with the wheels fully turned and with a rugged road surface.

Considering the factors mentioned above, the performance of the upright is significant because if it should break, the vehicle could lose the use of the wheel connected to it.

So, like most of the parts in the racing sector, the following aspects become all the more crucial:

- the need for additional rigidity (thus limiting buckling as much as possible),

- the lowest possible weight,
- maximum reliability and quality (and therefore safety).

The choice of titanium as the final material for the Epsilon uprights is due to the excellent compromise between the mechanical properties of the material and the density (specific weight) of this alloy compared to steel.

Sergio Rinland states: “We could have used machined Aluminium, Steel fabricated or MMC, but we chose Titanium as the best compromise Cost-Rigidity-Weight-Strength-Durability. And for our Titanium Uprights, we expect the whole season and more, that is 15,000 to 20,000Km ”

As far as the strategic decision on the production method is concerned, CRP Technology’s experience in the field of Rapid Casting was crucial.

Usually uprights are built using a combination of two technologies: some single components are machined from solid then these are welded to each other.

The limits of this process lie in the capacity to react to mechanical stress. With this method the parts are usually obtained from semi-processed pieces, which have an orientation of the molecular structure that works very well in one direction but badly in the others (anisotropic). Whereas casting, being isotropic, does not have a preferred structural direction and reacts in a similar way, even if a little less functional, however it is stimulated and is, therefore, safer.



Picture 12: Epsilon Euskadi eel1 on track

“Between one possibility entirely obtained from solid and one that is cast, with the CRP Rapid Casting method, the choice of producing mechanical parts by Titanium Rapid Casting is, first and foremost, due to greater flexibility during the design stage and to the possibility that it offers for obtaining greater effectiveness in structural behaviour; and secondly because it is also more economical” states Franco Cevoli, Chairman of CRP Technology.

But to produce a component using this method, the racing team’s partner, in this case CRP, must have exhaustive knowledge of the various materials and excellent command of the different construction processes that are used in succession. Naturally, synergy with the team’s technical project department is essential and, as a consequence, the knowledge of how the part works and therefore the performance required.

That is why this method, although extremely effective and efficient, is less widespread than other processes that are more outdated, less functional and often more expensive: the team needs an expert partner that can follow the entire process and bring it to a successful conclusion, with the utmost safety and quality. Therefore, they can no longer be considered simply suppliers of orders and based on a design, but much more. At present, very few in the world have been able to gain the same vast experience as CRP in this method, which indeed was first developed by them: 12 years experience in the motor sector at the highest levels guarantee that clients can be sure that they are getting the very best, with the highest levels of safety and with very few problems.

What is more, today CRP can reveal to the world one of its latest innovations which will help

it to further develop this process: Windform® PS, the all new polystyrene for disposable models.

The stages of the CRP method described below, together with a detailed description of the various phases, highlight the need for expert knowledge of plastic materials and metal alloys for making disposable models and finished parts, Rapid Prototyping processes, Reverse Engineering for quality control of all stages, engineering and FEM calculation, casting processes, CNC processing, non-destructive testing both during process phases and at the end of processing, CMM dimensional controls and much more, to guarantee the total and complete traceability of every part, from the certification of the metal alloy used to the certificate of final testing, before being mounted on the vehicle.

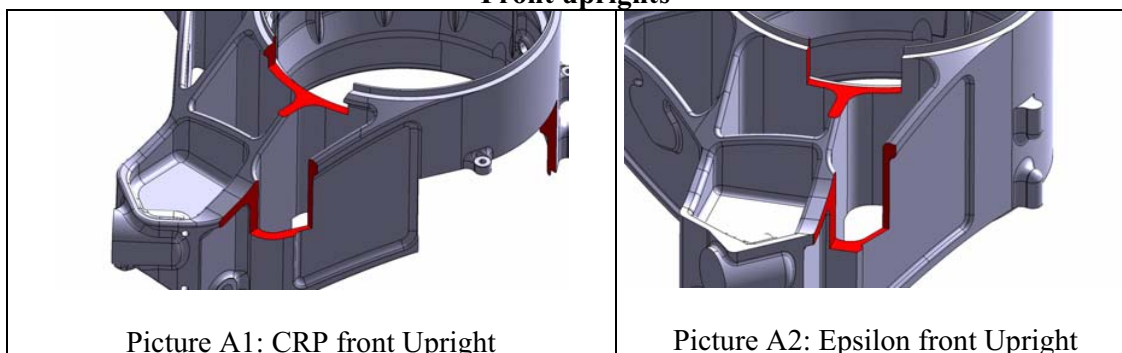
The engineering and manufacturing process

Sergio remembers: The Upright project with CRP started in anger in October 2007. Their input was massive, since they understood what it was needed and not only transformed the design into a ‘Casting Design’ but also made contributions towards the Stress Analysis improving the component rigidity, weight and strength as a consequence.”

Franco Cevolini, confirms, “Epsilon Euskadi provided us with an initial study that was characterised by a design that was well executed, simple and linear. Thanks to this preliminary study, our CAD department, together with the R&D department, was able to work in synergy with the client without any particular problems, so as to optimize mechanical performance and other various aspects of production, both during casting and the mechanical processing that followed.”

Thus some engineering modifications were made to the files given to us by the client, aimed at optimizing the design for the casting process and at improving final performance, in terms of rigidity, reliability and weight.

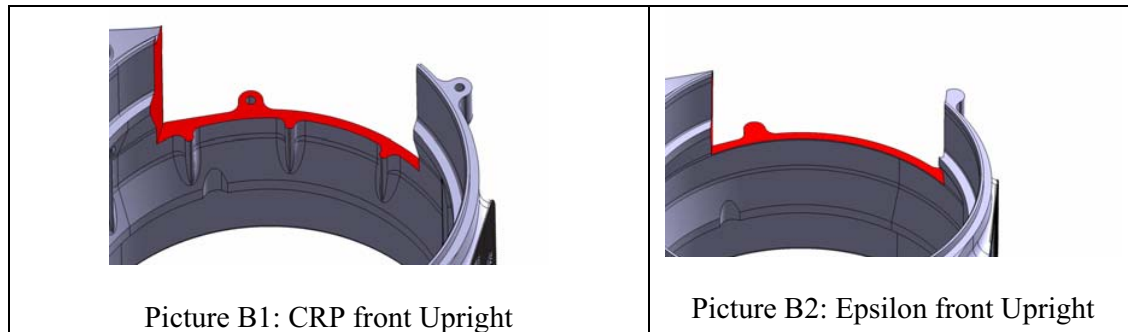
Front uprights



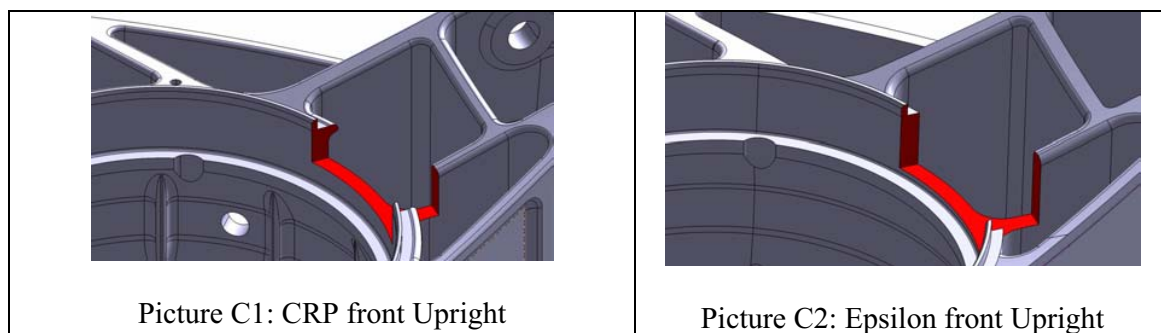
With reference to the pictures (A) shown above, you can see some of the initial modifications made to the cad drawing of the Epsilon front upright.

Picture A1 shows the 3D view of the front upright produced by CRP’s CAD department. One of the first modification concerns the presence, in the upper section, of a stiffening ring that was not present in the original version supplied to us by the engineers at Epsilon. The decision by our staff to introduce this “ring” was made for two reasons: firstly because it contributes to stiffening the shouldering area and secondly because it guarantees a greater room of intervention during the turning process.

In the lower section you can also see how an intervention was made to lower a thermal centre of gravity, whilst seeking more uniform thicknesses and increasing curvature.



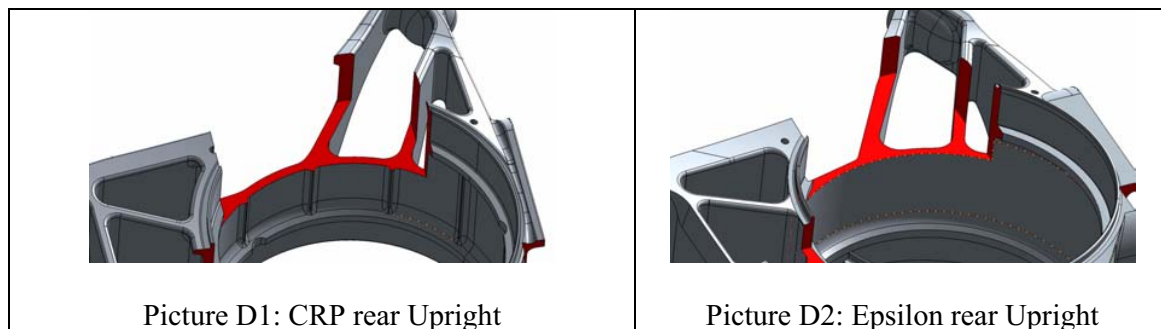
When comparing the two pictures B1 and B2, you can see an important modification: the addition, to the CRP drawing of ribs that connect the two shoulders. The aim is to stiffen the spool area.



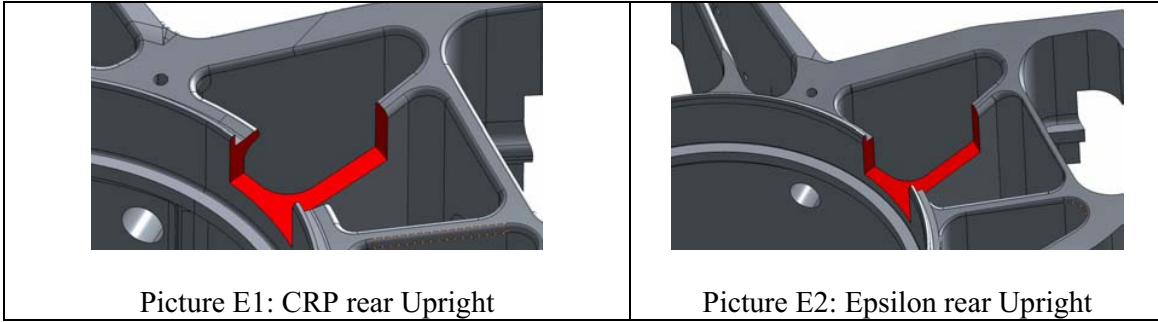
A further example of a modification made: in the section illustrated above, you can see a more noticeable stiffening ring (Picture C1), which in the original version (Picture C2) was not present, or rather, was not as noticeable. In addition to helping to stiffen the shouldering areas, it guarantees a greater room of intervention during the turning process.

Rear uprights

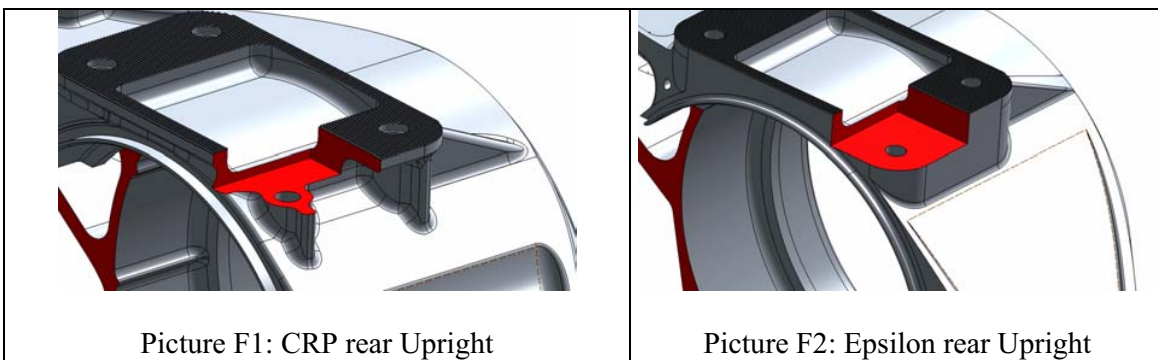
Further significant and effective modifications were made regarding the Epsilon rear uprights for the purpose of this project.



From the comparison of the two pictures D1 and D2, as for the front uprights, you can see the addition of ribs that connect the two shoulders in the file developed by CRP. The aim is to stiffen the spool area.



Also in the section illustrated in picture E1, you can see the stiffening ring that in the original Epsilon version (Picture E2) was not present. In addition to helping to stiffen the shouldering area, it guarantees a greater room of intervention during the turning process.



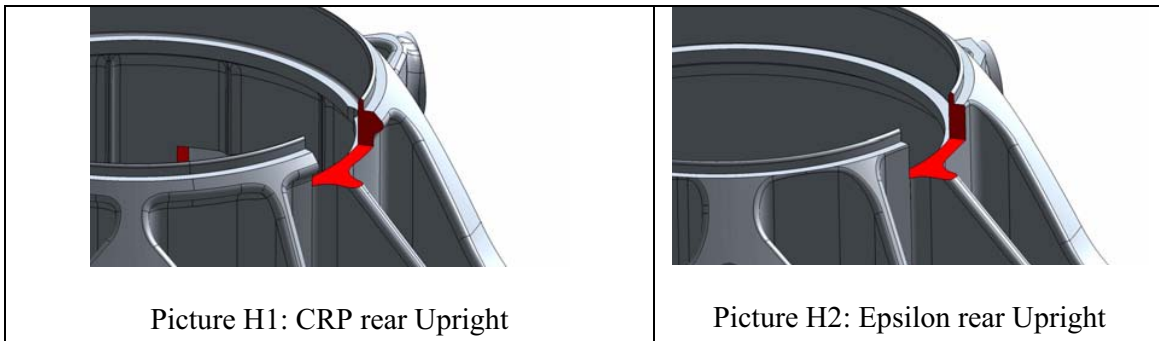
Pictures F1 and F2 highlight the work that was done to decrease the considerable initial mass underneath the top mounting point.

Such big masses (Picture F2) notwithstanding the adjacent thicknesses, during shrinkage (whilst slowly solidifying) contribute to generating strain that compromises the quality of the cast: cracks, porosity and deformation.

That is why we decided to intervene on the mass to reduce its volume as much as possible.



In this section, you can see how intervention was made to lower a thermal centre of gravity, by seeking more uniform thicknesses and increasing curvature (Picture G1/G2)

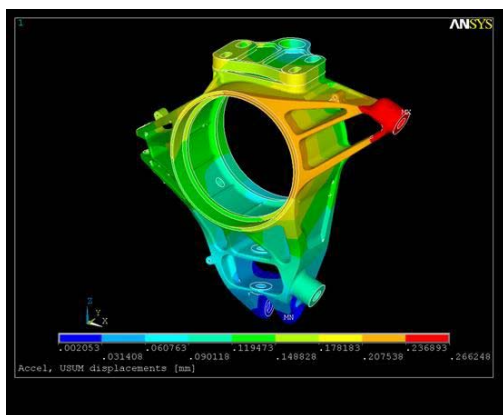


In this last view, once again, you can see the presence of the stiffening ring which was not present in the original Epsilon version (Picture H2).

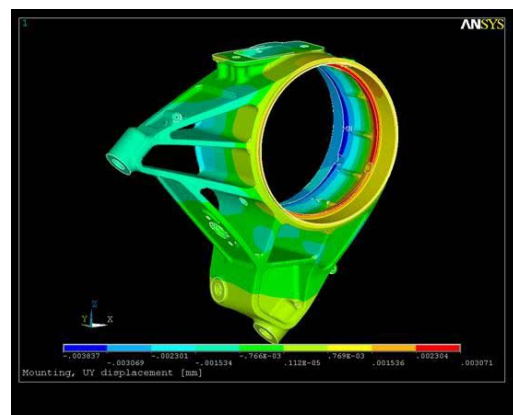
Once this detailed process of modifications was over we asked the client to verify that our requests did not clash with the requirements of their project.

With the endorsement of Epsilon's engineers, we moved in parallel to have a better idea of the behaviour of the piece stimulated by standard conditions of use.

Epsilon subjected the mathematic model to FEM analysis so as to identify the areas where room for improvement remained.



Picture 13: Rear Upright FEM analysis



Picture 14: Front Upright FEM analysis



Picture 15: Upright disposable model made with Windform® PS and Titanium Upright

The test was carried out on advanced workstations with the purpose of thoroughly examining the response to the most significant and varied factors of stress upon simulating the real behaviour in final working conditions.

With the feedback of the Epsilon engineers, we therefore perfected the 3D drawing to better distribute the strain and relieve those points that are subject to greater stress.

Following one final FEM session to guarantee the precision of the final modifications, CRP began the production cycle in keeping with its standard procedure: the RP department generated the disposable models, utilizing the new Windform® PS, upon which the relevant size control using 3D laser was carried out. The models were then sent to the foundry for the investment casting procedure. The rough castings then underwent H.I.P. treatment (Hot Isostatic Pressing), thermal treatments, dimensional control and setup for mechanical machining with 3D laser scanning. They were then CNC machined.



Picture 16: Epsilon Euskadi Titanium Casting Uprights

In the company's precision machining department, the CNC department (Continuous Numerical Control) finished the parts with NDT (Non Destructive Test) and 3D trials, then attached the ISO 9001:2000 certificates, thus allowing the uprights to be ready for mounting on competition cars.

"The opportunity to be able to decide between different manufacturing choices within the same company is essential for guaranteeing the best result possible. The flexibility of a highly elite and motivated staff also guarantees the reliability and respect for total production times" continues Engineer Cevolini.

Conclusion

Utilizing advanced rapid casting techniques is now a reality making complex castings as a viable alternative to CNC machining from billet and welded fabrication. The key to getting the most out of the technique will be to utilize the experience of a rapid casting source coupled with the design team to pull together the initial design and optimize the casting for the intended purpose. The feedback from CRP on the initial design from the "ee1" team yielded an increase in stiffness of the upright (between 5 to 8% depending on the area tested) with a mass reduction of 6%. The team was able to analyze and incorporate suggestions and receive a better performing part and install it on the car without issue. While this blending of a very old technique, investment casting, and rapid prototyping may no longer hold the "wow" factor seen with the advances in Direct Metal manufacturing, it is producing parts and components that race on tracks around the world and will be instrumental in manufacturing metal components for any highly competitive arena.